Soil Oribatei. I. Feeding Specificity Among Forest Soil Oribatei (Acarina)[1]

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ABSTRACT

Large numbers of living soil mites were obtained efficiently through extraction with Berlese funnels, collection in water, filtration through Buchner funnels, and separation from glass saucers following moderate drying. The foods used in the tests were (1) freshly fallen wood, conifer needles, and leaves, (2) these same substances in unknown but later stages of decay, (3) known species of wood decayed by known, uncontaminated species of fungi, and (4) individual species of uncontaminated fungi. Ten oribatid species were strictly fungivorous; eight fed primarily upon decaying wood and leaf tissues; and the remainder selected samples of each of the foregoing. The oribatids displayed considerable selectivity toward 20 species of fungi. Wood feeding could take place on *Pinus ponderosa* inoculated with *Lenzites trabea* only if at least a 6-week period of decay had elapsed; leaves of sugar maple, *Acer saccharum,* decayed with *L. trabea,* were amenable to oribatid feeding within a 2-week decay period. None of the organisms tested could feed on any fresh wood, needle, or leaf tissue, and none was observed feeding on dead oribatids, aphids, Collembola, or other animals.

Several investigators have indicated the numerical importance of Oribatei in forest soils (Bornebusch 1930, Evans 1955, Fenton 1947, Van der Drift 1951). The specific value of these organisms to forest soils has yet to be revealed, although there is no question of their importance in promoting soil fertility through trituration and digestion of organic matter. The purpose of this paper is to demonstrate in part the specific value of 20 species of Oribatei to soil fertility. This will be done by indicating the degree of food specificity among these organisms, including their role in feeding on decaying wood and leaf tissue.

Information regarding the feeding habits of Oribatei can be secured in three general ways. These are: (1) examination of the gut contents and observation of the feeding habits of the organisms in nature, (2) a study of the feeding habits of in-

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dividual species upon known foods, and (3) a study of the necessary biochemical constituents required for growth.

Upon using the first method, Jacot (1936) referred to Oribatei as saprophytes, Forsslund (1938) as fungivores and xylovores, and Pearse (1946) as vegetarians. More recently Weis-Fogh (1948), Van der Drift (1951), Riha (1951), and Wallwork (1957) could do no more than corroborate the former observations. The second method was used in this study. Each method of procedure is necessary in order to assess the role of Oribatei species.

MATERIALS AND METHODS

A technique was developed for efficiently obtaining large numbers of organisms. Oribatei were extracted from various size soil samples through Berlese funnels (Macfadyen 1953) and were collected in water. Although most oribatids will remain alive in the water for several days, it is best to remove them after 1 or 2 days. The upper layer of water containing most of the organisms and a little soil was filtered through a Buchner funnel. Oribatei were removed directly from the filter paper with a camel's-hair brush. The remainder of the soil-water extract also was filtered, and this filtrate was placed in a glass bowl and exposed to room temperature until the filter paper was dry. None of the mites were able to escape from this bowl and most of them were found on the surface of the bowl or on the underside of the filter paper, places from which they could easily be removed with a brush.

Specimens of the oribatids listed in table 1 were placed in stender jars which were kept in a desiccator (Sengbusch 1955) and stored in a constant temperature cabinet at 20° C. At least 20 adult specimens of each species were used with each test food. The test foods included the fungi listed in table 1 and others mentioned in the text, and fresh and decaying wood, conifer needles, and leaves. All fungi were prepared on a potato-dextrose medium of pH 5.6. A single food was tested at one time. Each test was repeated at least three times, and at least 1 week was allowed for determining feeding activity. The presence of stools indicated feeding and the relative number of stools indicated preferable food substances. The repeated absence of organisms from a food substrate together with the absence of stools was interpreted as a decisive repulsion of the mite by the food.

Three experiments were conducted. The first was designed to determine whether the species fed predominantly on wood, leaves, or fungi. In the second experiment xylophagous mites were given wood-decay fungi and wood infested with known wood-decay fungi as test food. The third experiment was designed to determine the stage of decay at which wood- and leaf-feeders will ingest the test foods, and whether the mites were able to feed upon modified components of wood including cellulose and an oxidized alkali extract of lignin.

Experiment I.—A list of test Oribatei and the test foods used in the first experiment is presented in table 1, with the results of this experiment. Six ob-

Table 1.—Feeding activity of forest soil Oribatei on various test foods.

	Test Foods[a]																	
Oribatei	Yeast T-131	*Rhodotorula* sp.	*Alternaria* sp.	*Aspergillus fumigatus* Fres.	*A. niger* van Tiegh	*Beauveria bassiana* (Bals.) Vuill.	*Cladosporium cladosporioides* (Fres.) deVries	*Homodendrum cladosporioides* (Fres.) Sacc.	*Epicocum* sp.	*Pachybasium niveum*	*Penicillium* sp.	*Phialophora mustea* Nurgaard	*Sporotrichum* sp.	*Stemphylium* sp.	*Syncephalastrum racemosum* Cohn ex Schroet.	*Trichoderma koningi* Oudem.	Decaying leaves, needles, and wood	Fresh leaves, needles, and wood	Type of feeder
1. *Belba kingi* n. sp.	R	R	R	R	R	R	A_1	A_2	F	R	R	A_2	F	A_2	A_2	A_1	F	F	Fu
2. *Camisia spinifer* (Koch)	R	R	F	R	R	R	A_1	A_2	F	R	F	A_1	F	A_1	F	A_2	A_2	F	WL?
3. *Carabodes areolatus* Berlese	R	R	R	R	R	R	A_2	A_2	F	F	F	A_2	F	A_2	F	F	A_2	F	Fu
4. *Ceratoppia bipilis* Hermann	R	R	F	R	R	R	A_2	A_2	F	—	F	A_1	—	A_2	F	F	F	F	Fu
5. *Ceratozetes gracilis* (Michael)	R	R	A_2	R	R	R	A_2	A_2	F	R	R	A_1	F	A_1	F	A_2	A_2	F	FuWL
6. *Eremobelba nervosa* n. sp.	R	R	R	R	R	A_2	A_1	A_2	F	F	R	A_2	F	F	A_2	A_1	F	F	Fu
7. *Galumna elimata* Koch	R	R	A_1	R	R	R	A_1	A_1	R	R	R	A_1	A_1	A_1	A_2	F	F	F	Fu
8. *Hermannia gibba* Koch	R	R	R	R	R	R	A_2	A_2	F	F	R	F	F	—	F	F	A_1	F	WL
9. *Hypochthonius rufulus* Koch	R	R	A_2	R	R	R	A_2	A_2	F	R	R	A_1	F	A_2	F	F	F	F	Fu
10. *Metabelba montana* (Kulcz.)	R	R	R	R	R	A_2	A_1	A_2	F	F	R	A_2	F	A_2	A_1	A_1	F	F	Fu
11. *Nanhermannia elegantula* Berlese	R	R	R	R	R	R	A_2	A_2	F	F	R	—	F	A_2	F	F	A_1	F	WL
12. *Nothrus biciliatus* Koch	R	R	R	R	R	R	A_2	—	F	F	R	A_1	F	A_2	F	F	A_1	F	WL
13. *Oppia nova* Oudem.	R	R	R	R	A_1	A_2	A_1	A_1	F	F	A_2	A_1	A_2	A_2	A_1	A_1	F	F	Fu
14. *Oribatula minuta* (Banks)	R	R	A_2	R	R	R	A_2	A_2	F	R	R	A_2	F	A_1	F	A_2	F	F	Fu
15. *Phthiracarus setosellum* Jacot	R	R	R	R	R	R	A_2	A_2	F	R	R	A_1	—	A_2	F	F	A_1	F	WL
16. *Platynothrus peltifer* (Koch)	R	R	R	R	R	R	A_2	A_2	F	F	R	A_1	F	A_1	—	A_2	A_2	F	FuWL
17. *Protoribates lophotrichus* Berlese	R	R	A_2	R	R	R	A_2	A_2	F	R	R	A_2	F	A_2	F	F	A_1	F	WL
18. *Pseudotritia ardua* (Koch)	R	R	R	R	R	R	A_2	A_2	F	R	R	A_2	—	A_2	F	F	A_1	F	WL
19. *Scheloribates pallidulus* Koch	R	R	A_2	R	R	R	A_2	A_2	F	R	R	A_2	F	A_2	F	F	F	F	Fu
20. *Steganacarus diaphanum* Jacot	R	R	R	R	R	R	A_2	F	F	R	R	F	F	F	F	F	A_1	F	WL

[a] A, acceptable; R, repellent; F, failed to feed but wandered over food. Subscripts 1 and 2 refer respectively to voracious feeding and feeding in small quantities. WL, primarily wood and leaf feeding; FuWL, primarily fungivorous but will feed on wood and leaf tissue; Fu, strictly fungivorous.

servations are especially noteworthy: (1) *Trichoderma koningi, Cladosporium cladosporioides, Phialophora mustea* and a species of *Stemphylium* were the preferred foods of all Oribatei classified in this study as strictly fungivorous. *T. koningi* was the preferred food to the adult belbids and by itself allowed the complete development of *Belba kingi,* whose life history has been studied by the author (Hartenstein, 1962a). (2) Some species of fungi were repellent to or not eaten by all species of mites. The *Rhodotorula* sp. of yeast, though rich in protein and vitamins, was perhaps too liquefied to be amenable to the feeding activity of the chelicerate oribatids. (3) *Beauveria bassiana,* an entomophagous fungus on at least 70 species of insects (MacLeod 1954), was consumed in small quantity by several oribatids. (4) *Aspergillus niger* and an unknown species of *Penicillium* repelled all oribatids except *Oppia nova.* Both the adult and its larvae fed upon the antibiotic-producer *A. niger.* (5) When all fungi edible to *Galumna elimata* were placed in a stender dish with this mite for the purpose of obtaining eggs, only *Syncephelastrum racemosum* served as the site for oviposition. Eggs were laid in this fungus during November, December, January, and February. (6) No oribatid was able to feed upon fresh wood, leaf, or conifer-needle tissue. On no occasion during the study period did any of these oribatids feed upon dead oribatids, aphids, Collembola, or other insects although many opportunities for such feeding activity were present.

The extent of fungivorous feeding is also indicated in table 1. Where possible, an estimate was made of the number of stools dropped by oribatids over a definite period of time. Using *G. elimata* as an example, if 30 or more droppings were counted per individual in 1 week, the fungus was referred in table 1 by the subscript "1" as having been eaten voraciously. Where less than five droppings were counted under the same environmental conditions, the subscript "2" was used. Since metabolic and feeding activities are specific characteristics, the size and number of droppings vary from species to species. Therefore, the subscripts 1 and 2 are only used to denote feeding activity of one oribatid species upon a species of fungus with that of the same oribatid upon another fungus.

There were three types of feeding habits observed among the Oribatei as indicated in table 1. Those whose well-formed stools consisted predominantly of wood or leaf particles when fed nothing but these substances, and which preferred such substances to any fungus placed simultaneously in the culture dish, are designated in table 1 as primarily wood- or leaf-feeding mites. A second type of feeding was displayed by *Platynothrus peltifer* and other mites designated as capable of ingesting and consuming wood and leaf tissue but preferring fungi. The remaining mites are classified as fungivorous. They were often found wandering over wood and leaf particles, but completed life history studies of *B. kingi,* n. sp., *Metabelba montana* and *Eremobelba nervosa* n. sp. (Hartenstein 1962a, 1962b), along with extensive observations of the other fungivorous species, furnish strong evidence to show that these mites merely graze upon the dead or growing microflora of decaying wood and leaves.

Observations of the feeding activity of the strictly wood- and leaf-feeding mites extended over an 18-month period. During this time it was noted that *Protoribates lophotrichus* preferred the parenchymatous tissue of decaying leaves and fed more vigorously upon sugar maple (*Acer saccharum* Marsh) leaves decayed with a heterogeneous assemblage of microorganisms in nature than upon the same leaves decayed aseptically with *Lenzites trabea* Pers. ex Fries for even a 6-month period in the laboratory. It preferred naturally decayed leaves to naturally decayed woody tissue or conifer needles. Although *Phthiracarus setosellum* and *Pseudotritia ardua,* among the phthiracarids, did periodically select certain fungi as food, *Steganacarus diaphanum* always preferred the xylem of coniferous needles and of the petiole of decaying leaves. Its eggs were often deposited in the latter in which the emerging larvae would develop to adulthood. Examination of conifer needles in which they fed revealed untouched vascular bundles and an epidermis with openings through which the phthiracarids made their entrance and exit. The camisiid *P. peltifer* preferred fungi to naturally decaying wood and leaves, but its willingness to devour large quantities of the latter when presented as its only source of food suggested that in nature it may be selective toward organic matter rich in fungi and other microflora. Forms from families closely related phylogenetically to this camisiid (Woolley 1958), viz., *Nothrus biciliatus, Hermannia gibba* and *Nanhermannia elegantula,* displayed feeding behavior similar to that of *P. peltifer* while a member of the same family, *Camisia spinifer,* although classified as a wood- and leaf-feeder, fed so slowly and infrequently as to preclude any positive assignment to feeding category. However, analyses of its intestinal contents and its habitat preference for leaves and wood did suggest that it feeds upon the latter in nature. Only intensive observations through life history studies will unequivocally determine its role in the decomposition of organic matter.

Experiment II.—Two brown- and two white-rot fungi were fed to five oribatids. At least 25 specimens of each species of oribatids were used with each fungus. The test oribatids included *B. kingi, O. minuta,* and *E. nervosa.* The fungi included the brown-rots *Poria monticola* Murr. and *Lenzites saepiaria* (Wulf. ex Fries) Fries, and the white-rots *Fomes pini* (Thore ex Fries) Karst and *F. applanatus* (Pers. ex Wallr.) Gill. Each test was conducted twice and at least 1 week was allowed for feeding. None of the fungi were eaten.

To determine whether oribatids will eat these fungi in association with wood, five pieces of wood inocu-

lated, respectively, with the brown-rot fungi *L. saepiaria* and *Poria incrassata* (Berk. and Curt.) Burt, the white-rot fungi *F. applanatus* and *F. pini,* and the blue stain *Ceratostomella* sp. were used as test foods. *P. lophotrichus* and *P. peltifer* were used as test organisms. Observations made 1 week and 1 month after introduction indicated moderate feeding activity upon all wood samples. Fungi removed from their woody substrate following autoclaving were consumed by the oribatids. Sugar maple (*A. saccharum*) leaves decayed with *L. trabea* (Pers.) were amenable to oribatid feeding within a two-week decay period.

Experiment III.—Samples of Ponderosa pine (*Pinus ponderosa* Laws) sapwood were fed to *P. lophotrichus* and *P. peltifer*. The samples had been decayed by the brown rot *L. trabea,* and included a control and samples for which the decay process was terminated at 2-week intervals beginning 2 weeks after inoculation and continuing through 14 weeks. Proximate summative analyses of the chemistry of the wood were reported by Klingaman (1960). Examination of the cultures revealed no feeding on wood samples at 0, 2, and 4 weeks of decay. Fecal pellets were found in all wood samples in the later stages of decay.

Observations throughout a 9-month period suggested that some of the oribatids may be able to obtain energy using lignin or cellulose as a carbon source. Oxidized lignin obtained as an alkali extract (Howard Smith Paper Mills, Cornwall, Ontario, Canada) was fed to various oribatids. *Steganacarus diaphanum* would not feed on the lignin but did survive beyond 2 months on the cellulose filter paper floor which was wetted periodically with a soil water extract. *P. lophotrichus* survived beyond 1 month on lignin and the cellulose floor. Lignin could be seen through the transparent wall of its larvae in the intestinal tract but whether any nutrient value was derived from the material could not be determined.

DISCUSSION

A preliminary attempt has been made to classify oribatid mites living in a limited geographical area according to their feeding habits. However, only a limited number of test-foods were offered in comparison to the wide diversity of foods in their habitats. Cleat (1952) was able to rear *Scheloribates laevigatus* on chicken feces, and Sengbusch (1955) cultured several *Galumna elimata* on *Protococcus.* The latter mite and *Scheloribates pallidulus,* which is closely related to *S. laevigatus,* have been classified in this paper as fungivores. For ecological purposes it may be justifiable to classify them as such and thus separate them from xylophagous forms. Such separation aids in the clarification of the roles played by individual species of Oribatei in the decomposition of organic matter.

The environmental conditions of oribatids are complex. The physico-chemical properties can be only vaguely defined due to enormous variability. In nature oribatids feed upon fungi and bacteria in all stages of development, complex faunal defecation products, and plant materials in various stages of decay. These materials and conditions cannot be duplicated in the laboratory. However, an understanding of the relationships between cellulytic, lignolytic, entomophagous and antibiotic-producing fungi of widespread occurrence in the soil and soil Oribatei can and must first be gained by laboratory study. The organisms are too minute for field study, and their microenvironments are too complex to attempt an evaluation of their role by measuring several physical variables with the intention of correlating these variables with oribatid density.

The importance of oribatids to forest soils has only been suggested in this work. The real value of oribatids in the decomposition of decaying wood and leaves can only be ascertained through an understanding of the mechanisms by which some are able to decompose these decaying substances and by determining those fractions of cellulose, lignin, and other components of wood that are broken down. A disclosure of the method by which some fungivorous oribatids are able to metabolize penicillin and other antibiotic producing fungi also may be significant.

Freshly fallen and decaying woods contain various amounts of cellulose, lignin, other carbohydrates, tannins, waxes, oils, amino acids, and other organic as well as inorganic components. Wood-decay fungi possess a high carbon content, a high percentage of chitin, free amino acids, sterols, and a high proportion of unsaturated free fatty acids (Cochrane 1958). What kind of substances must be removed or altered in fresh wood and what kind must be synthesized by the fungi and then incorporated into wood in order to make it palatable and nutritionally suitable for certain oribatids? This problem and those of the preceding paragraph can only be resolved through intensive work and ingenuity, through assay using growth and reproduction of Oribatei as criteria, and perhaps through a study of the enzymatic activity of intestinal symbionts upon various substrates.

It must be emphasized that the number of mites occupying a unit area of forest soil is great. Evans (1955) estimated 2.5 mites per cubic centimeter of soil in a spruce plantation. In the same volume of soil Wallwork (1957) estimated 2.35 mites in a hemlock forest. In view of their activities these mites are beneficial. Their value to forest soil fertility is important in consideration of their density.

REFERENCES CITED

Bornebusch, C. H. 1930. The fauna of the the forest soil. Forstl. Forsoksv. Danmark 11. 244 pp.
Cleat, N. 1952. Growth in the laboratory of economically important oribatid mites. Nature 169: 280.
Cochrane, V. W 1958. Physiology of Fungi. New York: John Wiley & Sons, Inc. 524 pp.
Evans, G. O. 1955. Identification of terrestrial mites. *In:* D. K. Kevan (ed.), Soil Zoology (pp. 55–61). New York: Academic Press, Inc.
Fenton, G. R. 1947. The soil fauna: with special

reference to the ecosystem of forest soil. Jour. Anim. Ecol. 16: 76–93.

Forsslund, K. R. 1938. Über die Ernährungsverhältnisse der Hornmilben und ihre Bedeutung für die Prozesse in Waldboden. Verh. VII. Internatl. Kongr. Ent. 3: 1950–7.

Hartenstein, R. 1962a. Soil Oribatei. II. *Belba kingi,* new species (Acarina, Belbidae), and a study of its life history. Ann. Ent. Soc. Amer., in press.

1962b. Soil Oribatei. III. Studies on the development, biology, and ecology of *Metabelba montana* (Acarina: Belbidae) and *Eremobelba nervosa,* n. sp. (Acarina: Eremaeidae). Ann. Ent. Soc. Amer., in press.

Jacot, A. P. 1936. Soil structure and soil biology. Ecology 17: 359–79.

Klingaman, R. 1960. Consecutive anatomical and chemical changes of Ponderosa pine sapwood decayed by *Lenzites trabea.* M.S. thesis, State University College of Forestry, Syracuse University, Syracuse, N. Y.

Macfadyen, A. 1953. Notes on methods for the extraction of small soil arthropods. Jour. Anim. Ecol. 2: 65–67.

MacLeod, D. M. 1954. Investigations on the genera *Beauveria* Vuill. and *Tritirachium* Limber. Canadian Jour. Bot. 32: 818–90.

Pearse, A. S. 1946. Observations on the microfauna of the Duke Forest. Ecol. Monogr. 16: 127–50.

Riha, G. 1951. Zur Ökologie der Oribatiden in Kalksteinboden. Zool. Jahrb., Abt. Syst., Ökol., Geogr. 80: 407–50.

Sengbusch, H. H. 1955. Studies on the life history of three oribatoid mites with observations on other species. Ann. Ent. Soc. Amer. (1954) 47: 646–67.

Van der Drift, J. 1951. Analysis of the animal community in a beech forest floor. Tijdschr. Ent. 94: 1–168.

Wallwork, J. A. 1957. The Acarina of the hemlock-yellow birch forest floor. Unpublished thesis, University of Michigan, Ann Arbor, Mich.

Weis-Fogh, T. 1948. Ecological investigations of mites and Collembola in the soil. Natura Jutlandica 1: 135–270.

Woolley, T. 1958. A preliminary account of the phylogeny of the Oribatei (Acarina: Sarcoptiformes). Proc. Tenth Internatl. Congr. Ent., Montreal 1956, 1: 867–74.